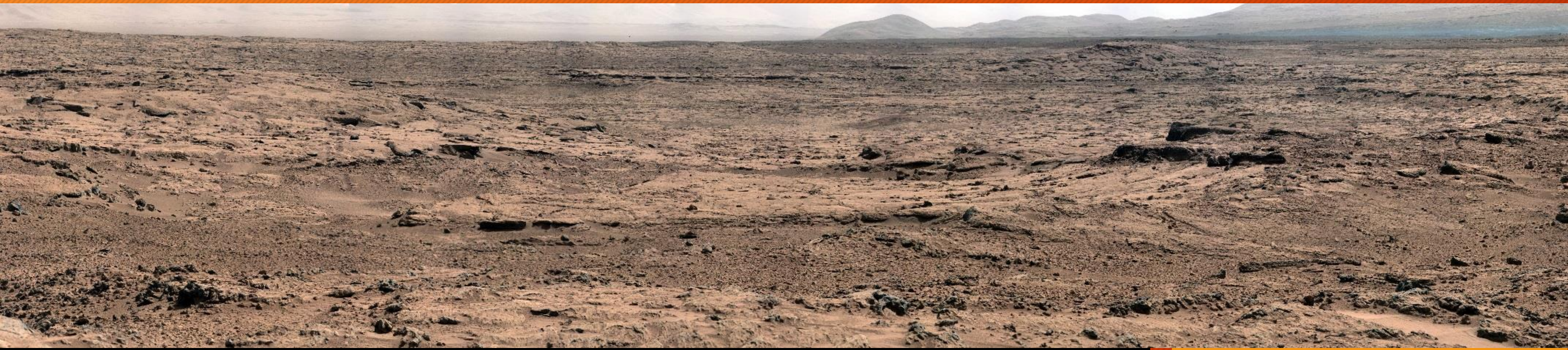


Mars
Pathways for Future Exploration

XM/Michelle Rucker
Mars Study Capability Team
NASA Johnson Space Center

Committee on Space Research (COSPAR) Workshop
Refining Planetary Protection Requirements for Human Missions
October 25-27, 2016
Lunar and Planetary Institute, Houston, TX

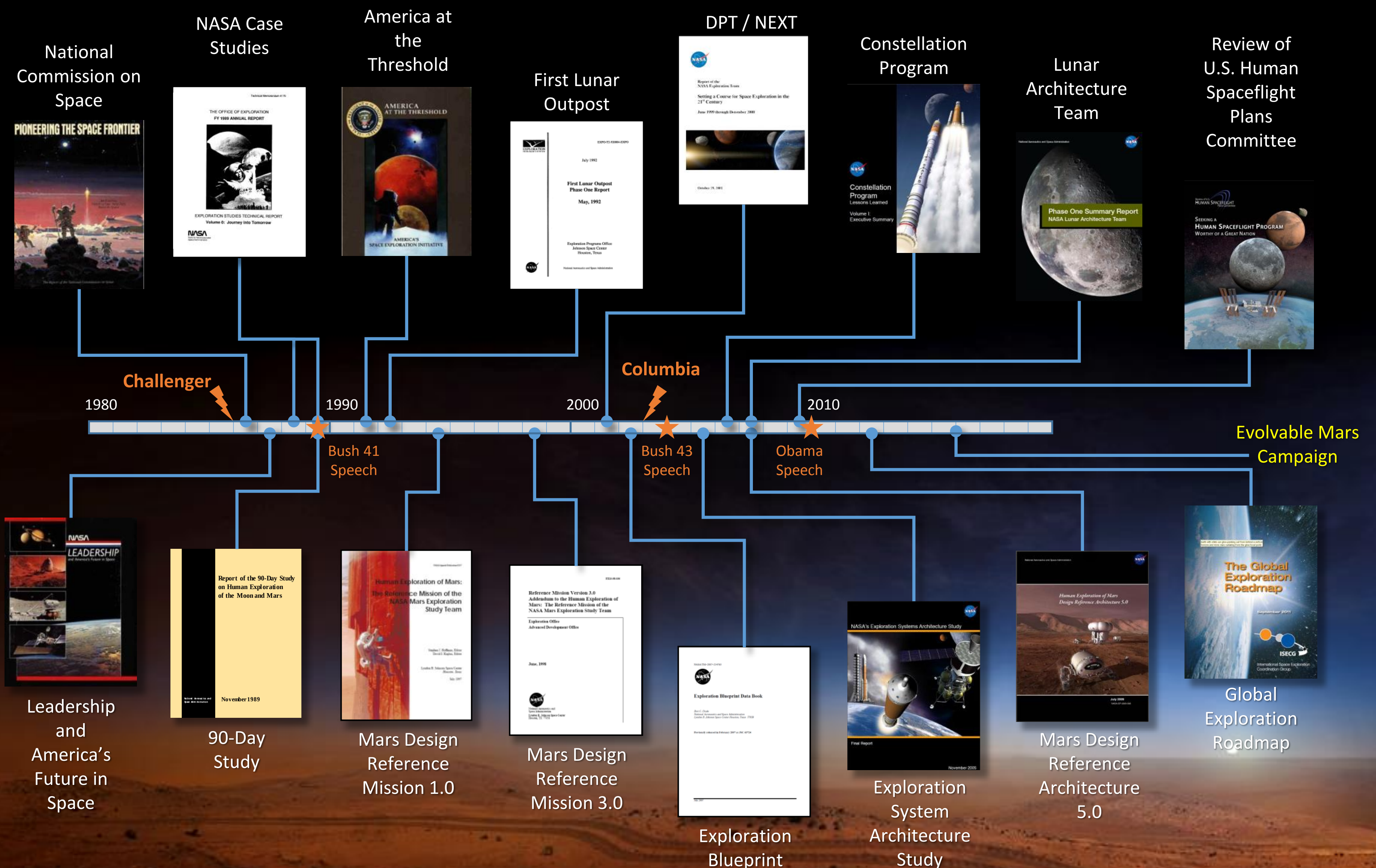
We have set a clear goal vital to the next chapter of America's story in space: sending humans to Mars by the 2030s and returning them safely to Earth, with the ultimate ambition to one day remain there for an extended time. Getting to Mars will require continued cooperation between government and private innovators, and we're already well on our way.

President Barack Obama
October, 2016

New! October, 2016: Mars Study Capability Team

- **Lead: John Connolly (NASA Johnson Space Center)**
- **Follow-on from Evolvable Mars Campaign (EMC)**
- **Reports directly to Jim Free, NASA Deputy Associate Administrator for Human Exploration and Operations Mission Directorate**
- **Charter Includes:**
  - Timely studies, decision analysis packages and data for NASA decision makers
  - Retain the knowledge and skills of NASA's many years of human Mars mission planning
  - Maintain and utilize an accessible, searchable library of human Mars mission design studies
  - Maintain reference Mars human architecture(s)
  - Coordinate with other exploration teams and NASA Mission Directorates
  - Maintain dialogue with commercial providers of Mars capabilities

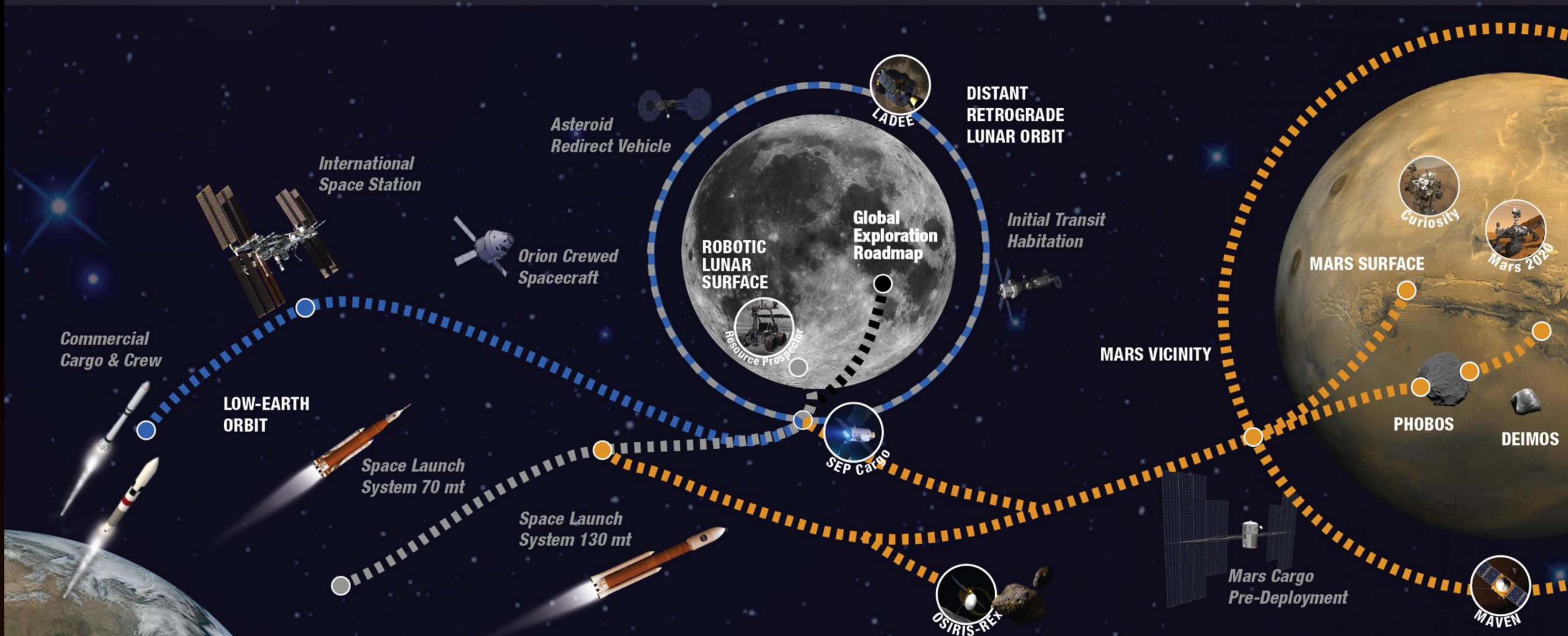
Human Exploration Beyond Low Earth Orbit



EVOLVABLE MARS CAMPAIGN

A Pioneering Approach to Exploration

EARTH RELIANT | **PROVING GROUND** | **EARTH INDEPENDENT**



THE TRADE SPACE

Across the Board | Solar Electric Propulsion • In-Situ Resource Utilization (ISRU) • Robotic Precursors • Human/Robotic Interactions • Partnership Coordination • Exploration and Science Activities

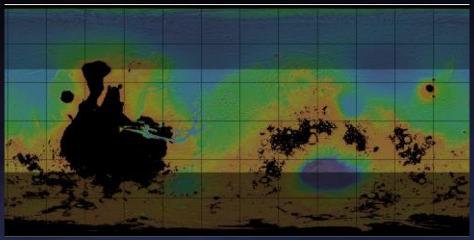
Cislunar Trades
- Deep-space testing and autonomous operations
- Extensibility to Mars
- Mars system staging/refurbishment point and trajectory analyses

Mars Vicinity Trades
- Split versus monolithic habitat
- Cargo pre-deployment
- Mars vicinity activities
- Entry descent and landing concepts
- Transportation technologies/trajectory analyses

Evolvable Mars Campaign
Human Mars Mission Concept Overview

- **Who? Humans**
  - The first humans to set foot on Mars are living among us today. For the purpose of system sizing analyses, we're currently assuming 4 crew per round-trip Expedition

- **What? Field Station**
  - Unlike Apollo, where we explored (and abandoned) several sites, it may be more affordable to establish a base where assets can be re-used. Subsequent expeditions could return to the same site, and use surface mobility assets to explore a radius of several hundred kilometers



- **Where? +/- 50º latitude**
  - NASA is conducting joint Human Exploration Office/ Science Mission Directorate landing site selection workshops to solicit public input on sites that are both accessible and offer scientific value or natural resources

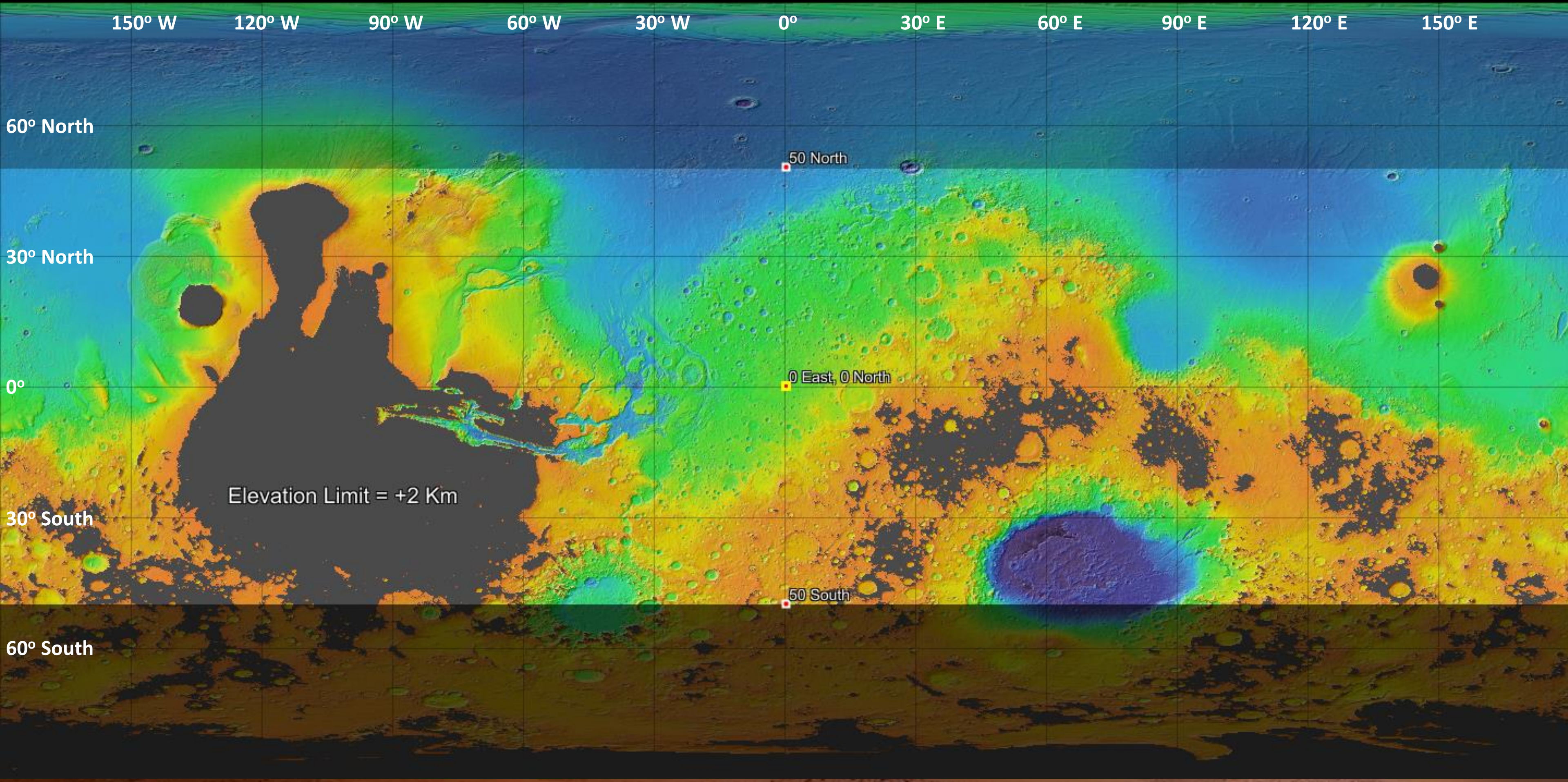
- **When? Late 2030's**
  - Each expedition crew would spend up to 500 days on Mars, and expeditions would depart from Earth every ~4 years

Mars Surface Exploration Terminology

- **Region of Interest (ROI)**
  - Areas that are relevant for scientific investigation and/or development/maturation of capabilities and resources necessary for a sustainable human presence
- **Exploration Zone (EZ)**
  - A collection of Regions of Interest that are located within approximately 100 kilometers of a centralized landing site
- **Latitude and Elevation limits**
  - Landing and ascent technology options place boundaries on surface locations
  - Preference for mid- to low- latitudes and mid- to low- elevations
  - Accessing water ice for science and ISRU purposes is attractive, leading to a preference for higher latitudes
  - Preliminary latitude boundaries set at +/- 50 degrees
  - Preliminary elevation boundary set at no higher than +2 km (MOLA reference)

Preliminary Mars Crewed Mission Constraints

Elevation Limit = +2 km   Latitude Limits = +/- 50º

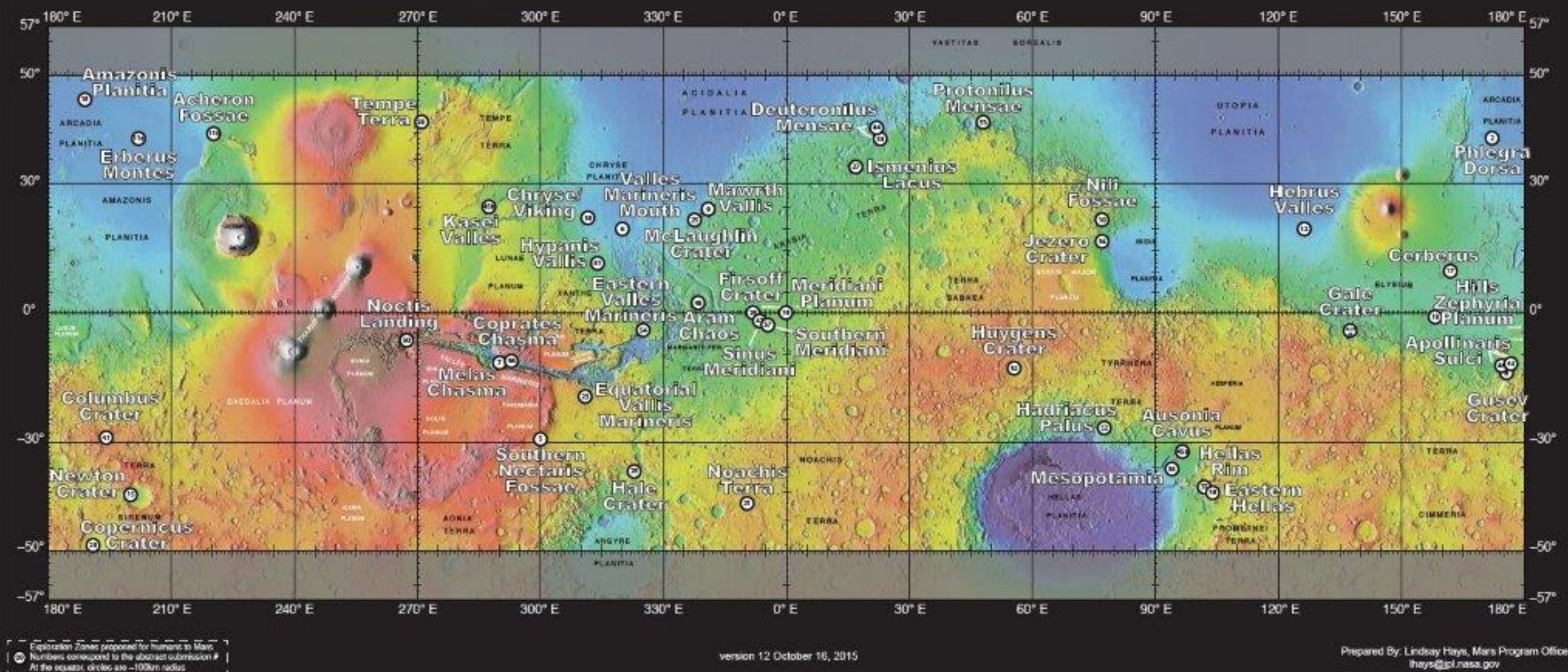


Mars Orbiter Laser Altimeter (MOLA) Color Legend

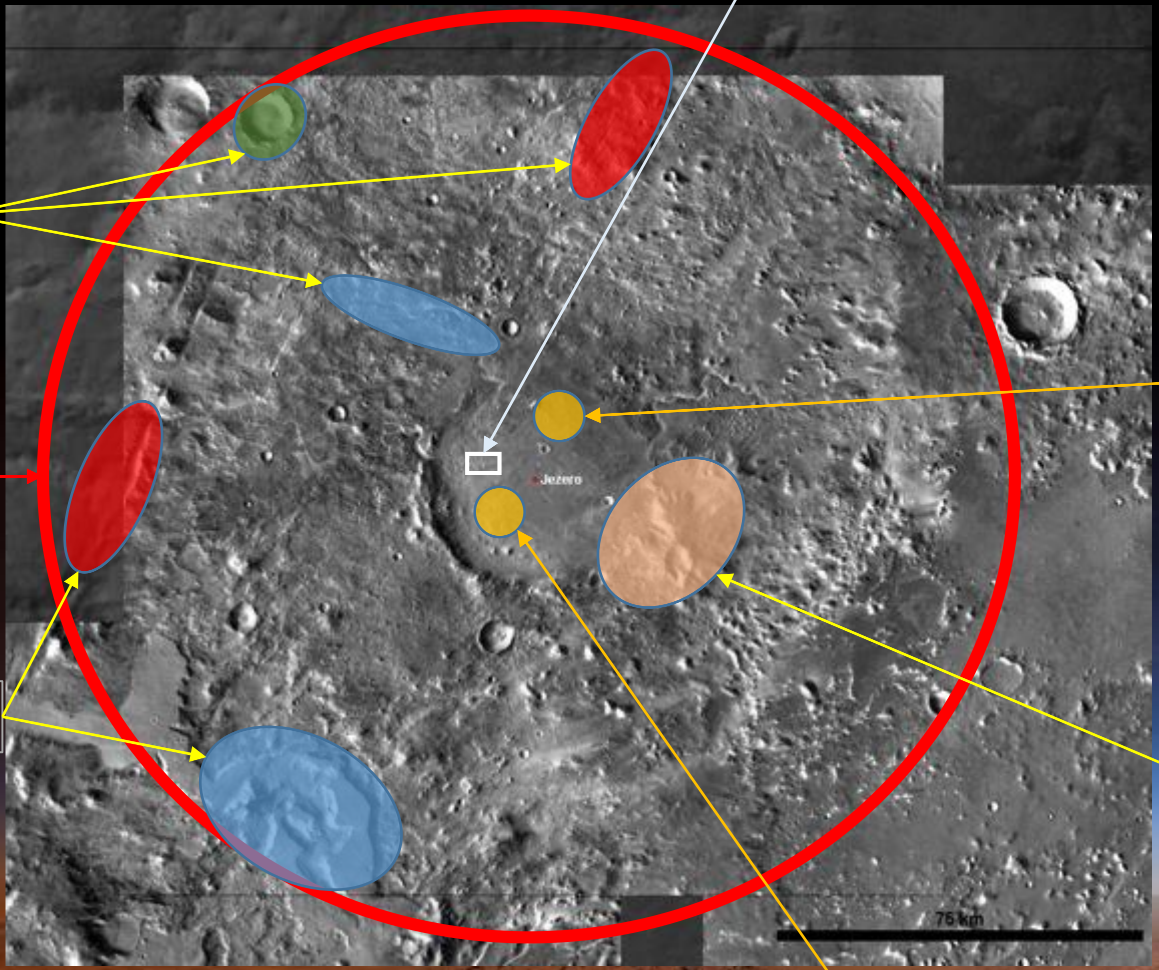
Exploration Zones Proposed at First EZ Workshop

This map is posted at http://www.nasa.gov/sites/default/files/atoms/files/exploration-zone-map-v10.pdf

Potential Exploration Zones for Human Missions to the Surface of Mars

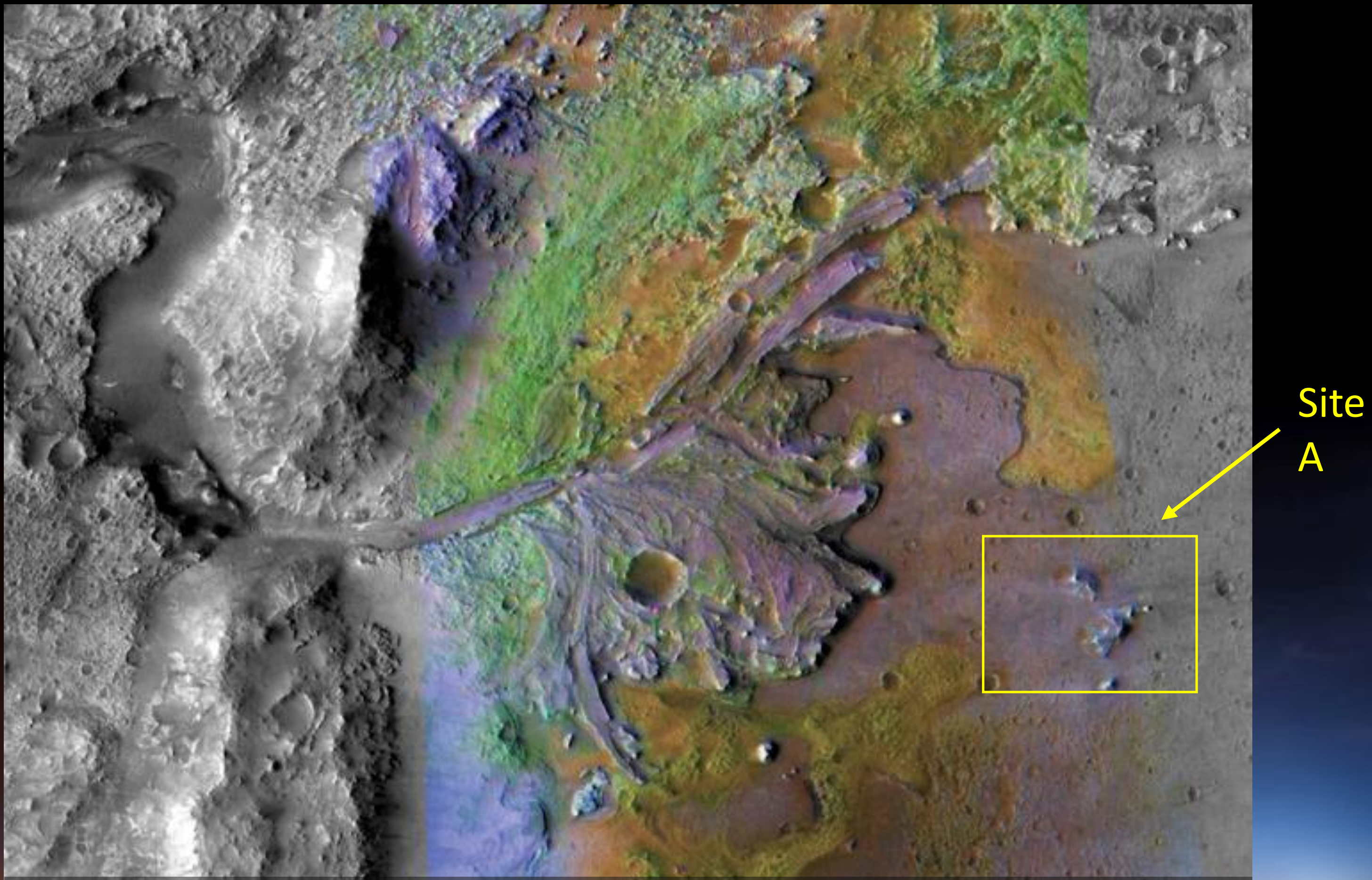


Example Mars Exploration Zone Containing Several Regions of Interest (ROI's)



Example of a Notional Field Station Buildup

We'll Use Jezero Crater in this example

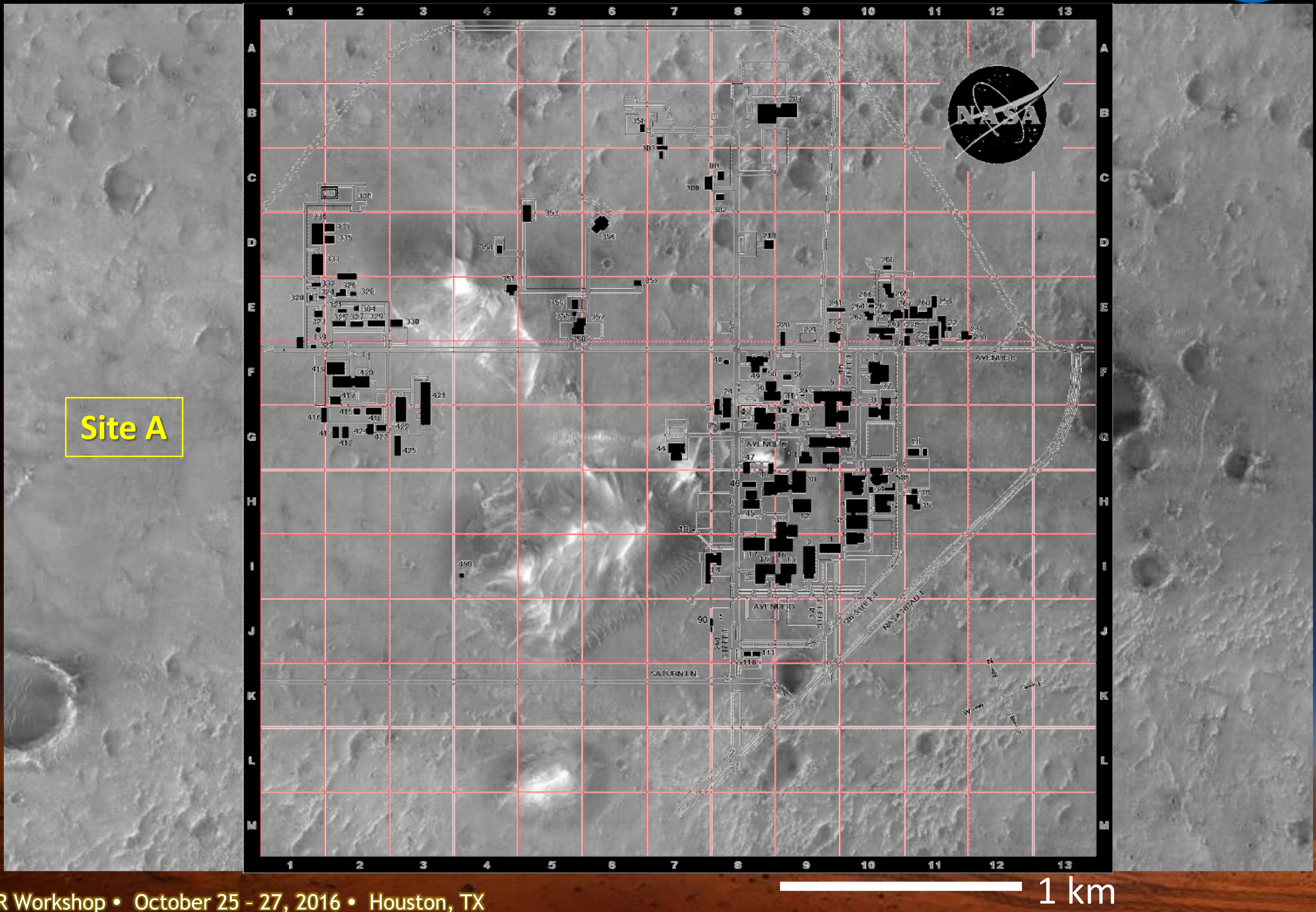


Jezero contains Fe-Mg smectite clay indicative of multiple episodes of fluvial/aqueous activity on ancient Mars, elevating the potential for preservation of organic material.

(Green = phyllosilicates, orange = olivine, purple = neutral/weak bands.)

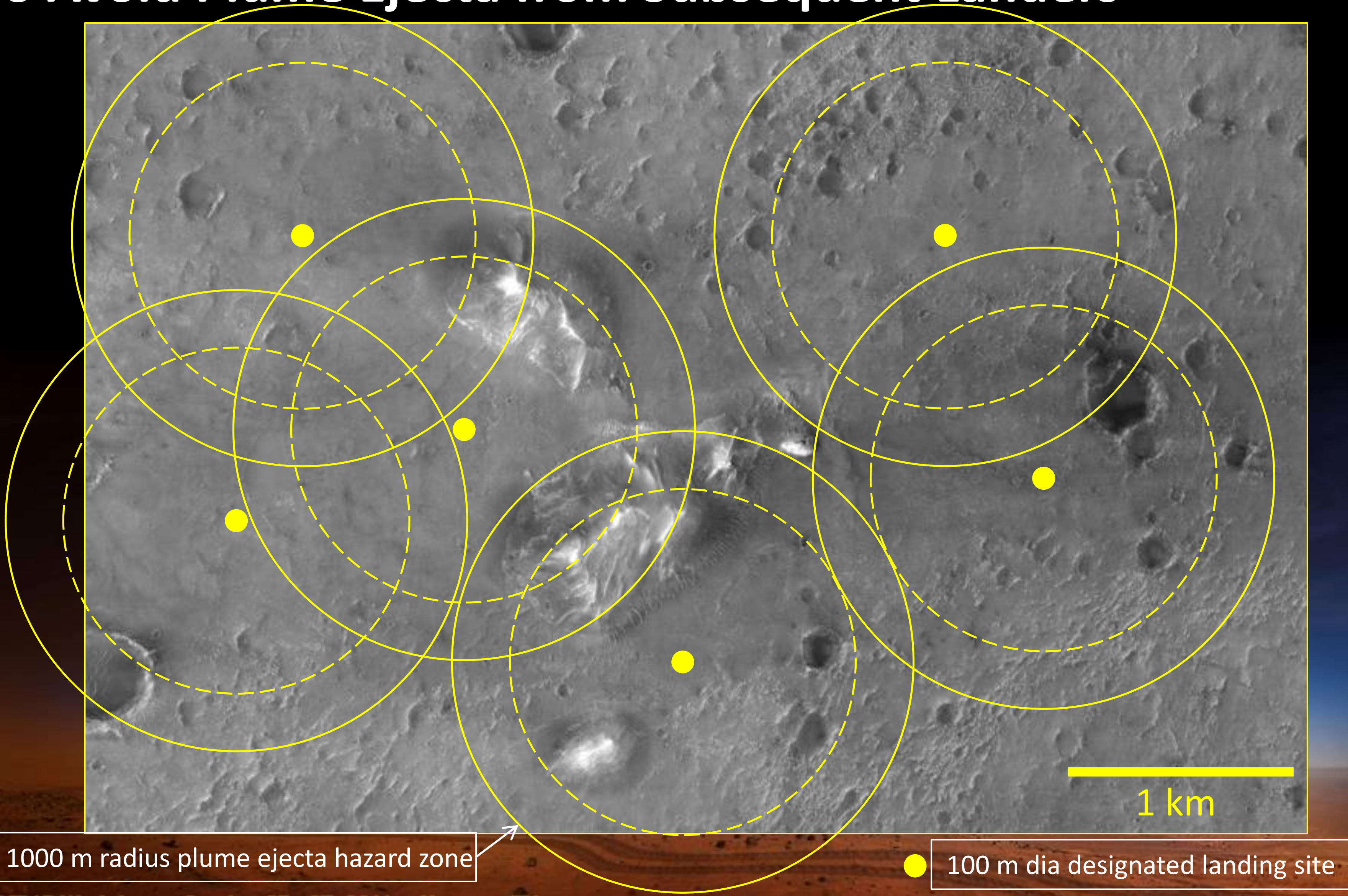
Image credit: NASA/JPL/JHUAPL/MSSS/Brown University (Ehlmann et al. 2008)

For Scale: Map of NASA's Johnson Space Center Overlaid onto Site A



Non-Interfering Landing Zones at Site A

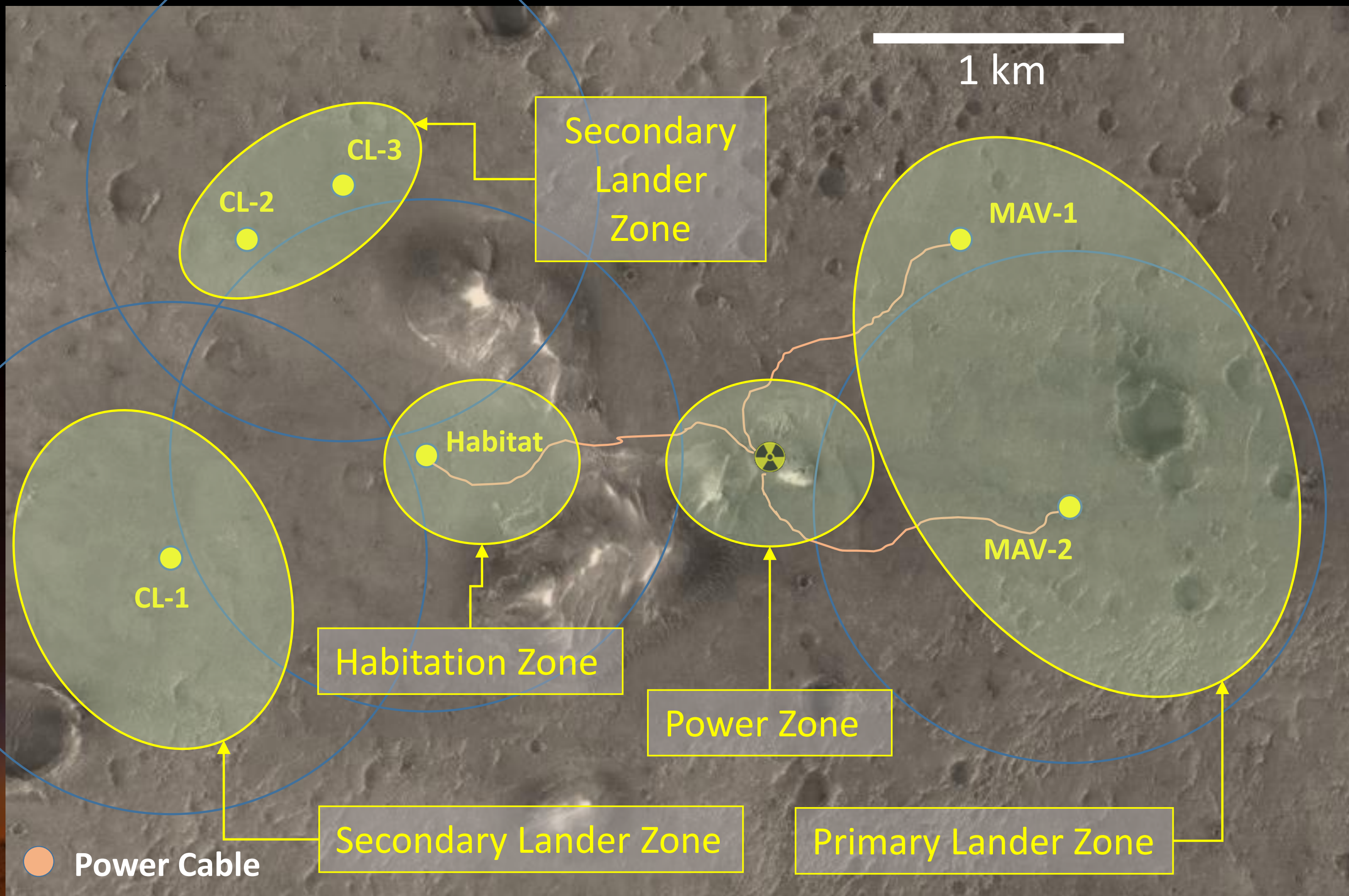
To Avoid Plume Ejecta from Subsequent Landers



Example of Field Station Layout with Specific Utilization Zones Identified

MAV
Mars Ascent Vehicle

CL
Crew Lander



(plume impingement *allowed* for retired hardware)

Notational Human Mars Concept of Operations
Based on Evolvable Mars Campaign Studies

1. **Launch unpiloted craft carrying non-perishable supplies and equipment**
   - May arrive at Mars years before crew departs Earth
   - Elements may include Phobos-Deimos exploration craft, or Mars landers carrying surface habitat, propellant production plant, power system, rovers, logistics containers
2. **Assemble the crew transit ship with several payloads launched years before crew departure**
   - Reusable, in-space habitat and propulsion system
   - Astronauts or automated systems connect the pieces and check out the craft
3. **The Mars crew launches from Earth and boards the transit ship, which then departs for Mars**
   - Depending on propulsion type and timing, transit journey is 6 to 9 months each way
4. **Once at Mars, options include a brief flyby, or any combination of an orbital mission, Phobos and Deimos encounters or landings, or a Mars landing with ground operations and re-launch to Mars orbit**
   - Orbital mechanics dictate that crew either begin the return journey to Earth within a few days of arriving, or they have to loiter in the Mars vicinity for 300 to 500 days

Notional Human Mars Concept of Operations
Based on Evolvable Mars Campaign Studies

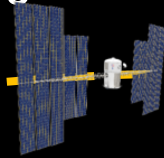
5. **For Mars surface operations: crew establish a fixed base for subsequent crews to return to**
   - Habitat, surface power
   - In Situ Resource Utilization (ISRU) to supply return propellants or life support oxygen and water
   - Crews use surface mobility systems to explore 100+ km radius from the base
   - Optional science laboratory to separate crew living area from science area
   - Crew collect and curate science return samples
6. **Crew depart in a Mars Ascent Vehicle (MAV), with return samples**
   - May use propellant derived from Mars resources
7. **MAV rendezvous with transit ship in Mars orbit**
   - MAV is placed in a disposal trajectory
8. **Transit ship returns to cis-lunar space**
   - Mars transit ship remains in orbit for use by subsequent crews
9. **Crew transfer to Orion and return to Earth**
10. **Subsequent crews return to the same site, taking advantage of existing infrastructure**
    - Landers must land at least 1 km from each other to prevent damage

Notional Human Mars Mission Architecture Elements

Based on Evolvable Mars Campaign Studies

Earth Launch System

Deliver payloads to cis-lunar space



In-Space Transportation and Habitat

Transport aggregated payloads and crew between Earth and Mars

Entry-Descent Lander

Land payloads on Mars

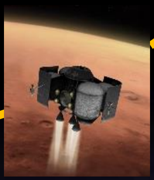
Orion

Transfer crew and cargo from Earth to cis-lunar space and back to Earth

Communications System

Earth-to-Mars, Mars surface-to-Mars orbit, and Mars surface-to-surface communication

Mars Ascent Vehicle



Transfer crew and cargo from the Mars surface to Mars orbit

Surface Habitat and Science Lab

Sustain 4 crew for up to 500 days per Expedition

Logistics Carrier

Deliver equipment and consumables

Surface Mobility

Planetary Space Suits and robotic or pressurized rovers

Surface Utilities

Power, In Situ Resource Utilization

Planetary Protection Considerations

- How “open” can our life support architectures be?
  - Apollo, Shuttle, and Space Station all vented crew cabin air and waste overboard
- How do we safely dispose of decommissioned equipment?
  - Abandoned space suits, propellant tanks, Mars Ascent Vehicles
- How close can we land to areas where life may be/have been present on Mars?
  - Will we have to sterilize our rovers before we venture out on excursions?
- How do we operate near liquid water?
  - Particularly In Situ Resource Utilization operations
- What must we do to mitigate spacecraft-induced environments around our crewed vehicles?
  - Will this drive our allowable leakage requirements?
- How will we sterilize sample return containers?
- How will we verify any of this?

Key Takeaways

- NASA's goal is to send humans to Mars in the 2030's
- Current focus is on evaluating different approaches so we can make good technology investment decisions
- Evolvable Mars Campaign has concentrated on a single landing site approach
  - Vs. DRA 5's Apollo-like, multi-site approach
- NASA recently chartered the Mars Study Capability Team to assess missions from cis Lunar space to Mars and back

For More Information, Contact

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Questions?